Article

Transport versus on-farm slaughter of bison: Physiological stress, animal welfare, and avoidable trim losses

Robert McCorkell, Katherine Wynne-Edwards, Jayson Galbraith, Al Schaefer, Nigel Caulkett, Soren Boysen, Ed Pajor, and the UCVM Class of 2012

Abstract — Ranched bison are typically less acclimated to handling than are domesticated livestock, suggesting that they might be more vulnerable to handling and transportation stressors. Grain-finished bison were slaughtered on-farm (n = 11), or held for 48 h, transported to a research abattoir, held in lairage for 18 h, and then slaughtered (n = 11). An additional group (n = 10) was sampled at a conventional fixed location abattoir. Measures included serum cortisol and corticosterone concentrations during on-farm handling and exsanguination, serum glucose, creatinine phosphokinase (CPK), aspartate aminotransferase (AST), and trim losses. Transport was associated with an increase in trim loss. On-farm, glucose was elevated, CPK was positively associated with handling order over 12 h, and corticosterone concentration, although lower than cortisol concentration, showed a greater response to prolonged disturbance. With appropriate on-farm handling facilities, the use of on-farm slaughter and mobile abattoir could avoid muscle damage and trim losses, and mitigate injuries sustained during handling and transport of bison.

Résumé — Transport ou abattage des bisons à la ferme : stress physiologique, bien-être animal et pertes de viande évitables. Les bisons élevés dans un ranch sont habituellement moins accoutumés à la manipulation que le bétail domestiqué, ce qui suggère qu'ils sont plus vulnérables aux facteurs de stress liés à la manipulation et au transport. Des bisons engraissés au grain ont été abattus à la ferme (n = 11), ou détenus pendant 48 h, transportés à un abattoir de recherche, mis dans des installations d'attente pendant 18 h, puis abattus (n = 11). Un groupe additionnel (n = 10) a été échantillonné à un abattoir fixe conventionnel. Les mesures incluaient les concentrations de cortisol sérique et de corticostérone durant la manipulation et l'exsanguination à la ferme, le glucose sérique, la créatinine phosphokinase (CPK), l'aspartate aminotransférase (AST) et les pertes de viande. Le transport était associé à une hausse de la perte de viande. À la ferme, le glucose était élevé, la CPK était positivement associée à l'ordre de manipulation pendant 12 heures et la concentration de corticostérone, quoique inférieure à la concentration de cortisol, a montré une réponse plus élevée lors d'une perturbation prolongée. Avec des installations de manipulation à la ferme appropriées, l'utilisation de l'abattage à la ferme et d'un abattoir mobile pourrait éviter les dommages musculaires et les pertes de viande et atténuer les blessures subies durant la manipulation et le transport des bisons.

(Traduit par Isabelle Vallières)

Can Vet J 2013;54:769–774

Faculty of Veterinary Medicine and the Pain and Animal Welfare Research Group, University of Calgary, Calgary, Alberta (McCorkell, Wynne-Edwards, Caulkett, Boysen, Pajor, UCVM class of 2012); Alberta Agriculture and Rural Development, Camrose, Alberta (Galbraith); Agriculture Canada, Lacombe, Alberta (Schaefer).

The UCVM Class of 2012 includes the following DVMs: Adelman, Lauren; Ames, Emily; Anderson, Stephanie; Atkin, Dale; Berard, Brooke; Bosnyak, Monica; Chalmers, Carli; Clancy, Eoin; Doering, Clinton; Elliott, Amanda; Eslinger, Alyssa; Hanak, Eryn; Heck, Erin; Hering, Adam; Holt, Jordan; Hutchinson, Amber; Jajouei, Maryam; Kirby, Ashley; Klugkist, Dennis; Larison, Clarice; MacQuarrie, Heather; Manson, Layne; Olesen, Tegan; Perez, Adrien; Risling, Tara; Rose, Nicole; Shacker, Kelsey; Shields, Erin; Smith, Taylor; Sparkman, Katherine; Tannahill, Melissa.

Address all correspondence to Dr. Robert McCorkell; e-mail: robert.mccorkell@ucalgary.ca

Bison are the largest land mammals native to North America and, prior to European settlement, they ranged widely over the continent in numbers estimated to be greater than 30 million (1). The species was driven to near extinction by the end of the 19th century through hunting and loss of habitat (2). The numbers of bison have rebounded so that at the beginning of the 21st century there were approximately 500 000 bison (3) in North America. Most of these bison are located on commercial farms that raise the animals for meat production. In Canada, there are approximately 125 000 bison on 1200 farms, with 77% of the farms located in the provinces of Saskatchewan and Alberta (4).

Bison meat is a niche product that attracts a high value in the marketplace (5,6). Access to desirable interprovincial and international markets for bison meat is limited by meat inspection legislation that requires animals to be slaughtered in federally licensed facilities, which are rarely located near bison farms (7,8). Thus, bison intended for slaughter need to travel long distances for the product to have access to high value markets (9).

Animal welfare is a serious consideration whenever animals are transported (10,11). Assembly, loading, travel time, unloading, regrouping, temperature fluctuations, and introduction to novel surroundings are all associated with increases in physiological stress, as measured by behavior, heart rate, respiration rate, rectal temperature, and concentrations of serum cortisol and plasma epinephrine (12,13). Bison are more flighty and fearful than cattle and transportation and handling of bison is particularly difficult due to their relatively large flight zone, strong herd instincts, and aggressive nature (14).

Bison are most commonly raised in extensive management systems designed to require a minimum of animal handling, and most commercial bison have not had their horns removed (15), increasing the potential for injury in closed spaces such as a trailer. In Canadian cattle, bruising losses to the beef industry are approximately 5 million dollars per year (15). The overall cost of bruising is due to the loss of edible parts, labor costs to trim the bruising, and value depreciation of the carcass (16). Pre-slaughter bruising is also an indicator of animal welfare during the immediate pre-slaughter period (15–17). These factors create conditions in which bruising is more likely in bison than in cattle and, when combined with physiological challenges and psychological disruptions, negatively affect carcass yield and meat quality (13,17,18).

One possible solution to the problems associated with transport is to use an on-farm slaughter and mobile multi-location abattoir to process the bison on the farm of origin (15,19,20). This would eliminate transport, exposure to unfamiliar facilities and animals, and the need to withhold feed and water prior to slaughter. Mobile abattoirs usually consist of a semi-trailer in which the interior has been modified to include the components necessary to provide slaughter, inspection, and refrigeration needs in compliance with the applicable legislation.

The objectives of this study were to compare the slaughter of bison on-farm using a mobile multi-location abattoir with the slaughter of bison at a fixed location research abattoir as well as a conventional facility, by measuring indicators of stress (serum cortisol and corticosterone), muscle injury [serum aspartate aminotransferase (AST) and creatine phosphokinase (CPK) concentrations], and economic losses before final weight determination for value (trim loss).

Materials and methods

Study design

Three groups of bison were sampled: i) On-farm: on-farm slaughter with processing in a mobile abattoir; ii) Research facility: bison from the same farm population transported to a research abattoir; and iii) Conventional: an independent group of bison heifers sampled at a conventional abattoir. Twenty-two bison heifers, aged 26 to 30 mo and born, raised, and grain-finished (oat ration, mixed hay, and salt/mineral supplement) on 1 northern Alberta ranch were purchased *in situ* and divided across the first 2 groups. Over a single 12-h interval in October of 2010, the animals were sequentially moved through the on-farm handling system and briefly captured in the squeeze chute to obtain a serum sample from the tail vein. After handling, each animal was alternately assigned to a common pen and destined for transport to the research facility (n = 11), or moved into a confined area of the handling system and killed for processing in a mobile abattoir (53′ trailer) licensed in the province of Alberta (n = 11). The interval from first disturbance in the morning, to last individual killed, was 8 h. The group destined for transport to the research facility were left undisturbed in the common pen for 36 h, and then moved through the on-farm handling system for identification and loading onto a trailer. After transport, heifers were off-loaded into lairage in groups of 2 or 3 in the Meat Research Facility at Lacombe, Alberta. Slaughter began approximately 18 h later and was completed in 3.5 h. The third group of 10 heifers, from a single source, and also grain-finished, was sampled at a fixed location, provincially licensed abattoir. All meat was certified and entered the food chain following the research.

On-farm handling facility

The on-farm handling facility was designed for bison, and holding pens for grain finishing were equipped with solid sides. The chute system allowed animals through to a squeeze chute that had solid walls on one side, but was visually open to other holding areas on the other. All holding areas were open to the sky. As it was not possible to open the squeeze-chute sides for extraction, animals destined for on-farm slaughter were moved back into the chute system after sampling and then were killed by an intracranial shot from a 12-gauge shotgun with a 2 ¾ inch foster slug (1 ounce). Immediately after death, the carcass was hoisted by 1 hind limb, transported approximately 200 m, and exsanguinated, at which point a mixed jugular vein and artery serum sample was obtained. The carcass was then transferred into the mobile abattoir facility where it was skinned and eviscerated. Weight was obtained after splitting the carcass, and again after trim of the split carcass, as the "hot hanging" weight entering the chiller. A provincial inspector monitored trim for certification on-farm.

Transport

The holding capacity of the transport trailer was 12 heifers, and 11 were distributed across 3 interior chambers. Total transport

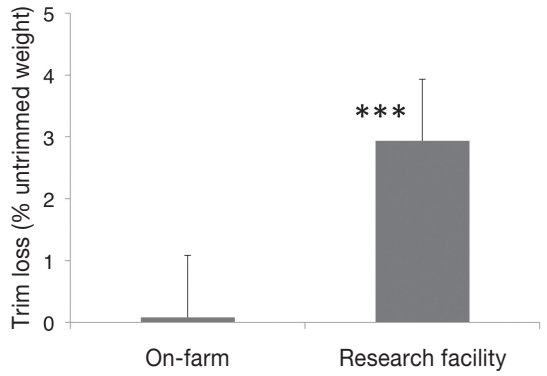

Figure 1. Proportional carcass weight change as a result of trim to remove bruises and injuries for heifers slaughtered on-farm and at the research facility. Asterisks indicate a significant difference ($P < 0.0001$). Trim losses could not be quantified at the conventional abattoir.

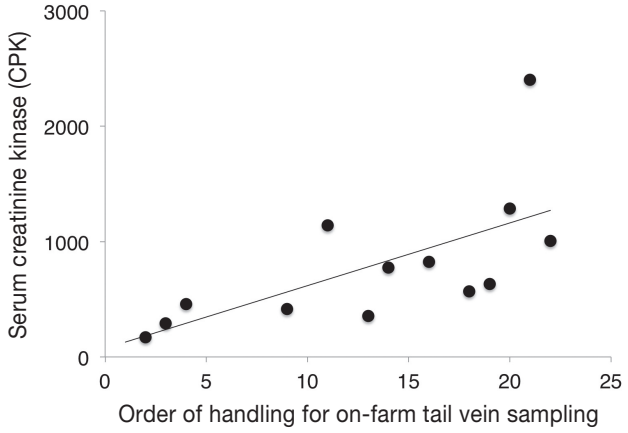

Figure 2. Positive association between order of handling, as a proxy for the duration of disturbance within the day on-farm, and CPK, as an index of muscle damage.

distance was approximately 275 km and lasted 6 h from loading through to unloading. Weather conditions during loading were overcast, with a mean temperature of 1.1°C at loading and 2.5°C at off-loading, with scattered light snow.

Research facility

The Agriculture Canada abattoir is federally licensed and housed only the 11 research heifers. A federal inspector monitored trim for certification. A mixed jugular serum sample was obtained during exsanguination, immediately after an intracranial rifle shot (223 caliber). Weight was recorded at the same stages as at the on-farm site.

Conventional facility

Single source, grain-finished heifers (n = 10 in the group) had been in lairage for 9 h before they were moved for slaughter. The adjacent pen also contained about a dozen bison, obtained as a mixed lot at auction, including a bull. Cattle were also present within the same facility. Mixed jugular serum was obtained during exsanguination, immediately after a rifle shot (caliber unknown), in the same manner as the other 2 groups. The facility weighing station was located after the trimming site, which did not correspond to the other 2 facilities. Thus, trim losses could not be calculated.

Student observers completed focal animal check-sheets for each animal in the initial passage through the on-farm handling system, reporting the presence or absence of rearing, kicking, and direct aggressive interactions with other individuals. In addition, visible damage was recorded while the animal was restrained for blood sampling. No behavioral observations were conducted during loading for transport, off-loading, or subsequent handling.

Serum biomarkers

During exsanguination, mixed jugular blood samples were collected by free catch into serum separator tubes. Blood was immediately drawn from the separator tube and transferred into pre-heparinized 1-mL syringes for blood glucose analysis using an I-STAT machine and CG6+ cartridges (I-STAT, Abbot Laboratories, East Windsor, New Jersey, USA). Serum was frozen and sent to a reference laboratory for AST and CPK analyses (Antech Laboratories, Calgary, Alberta). Cortisol and corticosterone were quantified by liquid chromatography–tandem mass spectrometry (LC-MS/MS) after zinc sulfate protein precipitation using a research laboratory method validated for diverse vertebrate species (21).

Statistical methods

Statistical analyses were conducted using analysis of variance (JMP version 9.0; SAS, Carey, North Carolina, USA) with the threshold for significance set at 0.05. All variables were checked for normality and for equality of variance and statistical tests appropriate for the measures were used. Details are presented in the results.

Results

Behavioral observations

Ten of the 22 bison had adverse behavioral responses to the handling, ranging from a horn de-gloving to kicking and rearing in the chute. Bison with adverse behavioral events on-farm did not have more bruising, trim losses, or higher cortisol than the other animals sampled on farm that day, or the integrated group of 22 with a tail vein sample from the squeeze chute.

Trim loss

Animals killed on-farm yielded carcasses with little to no trim loss (0.22 ± 0.25 kg). In contrast, all carcasses suffered trim losses after transport to the research slaughter facility [7.22 ± 0.86 kg; t (unequal variances) = 7.79, df = 11.72, $P < 0.0001$], ranging from 3.2 to 14.2 kg. As a percentage of carcass weight after splitting into sides, this represents negligible loss on-farm (only 0.1%) relative to slaughter at the research facility after transport [t (unequal variances) = 7.61, df = 11.20, $P < 0.0001$; Figure 1]. Although the trimmers differed at the 2 sites, inspector oversight, and the financial incentive of selling the meat back to market, were factors shared across sites. There was no

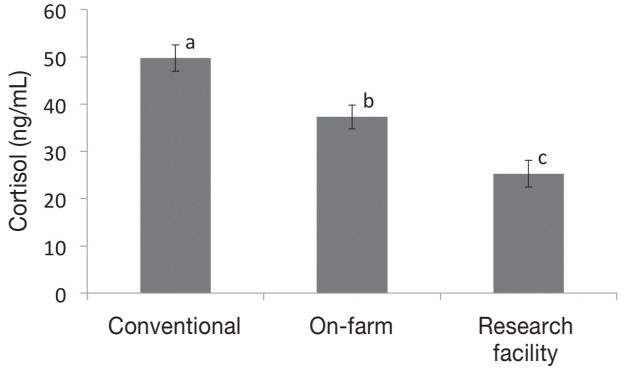

Figure 3. Cortisol concentration (ng/mL) in exsanguination serum at a) fixed location abbatoir after transport and lairage (conventional), b) after on-farm slaughter in a mobile abbatoir following handling to obtain a tail vein sample (on-farm), and c) after on-farm handling for tail vein sampling plus transport and lairage at a research slaughterhouse facility (research facility). Different lower case letters indicate significant *post hoc* differences by Tukey-Kramer HSD.

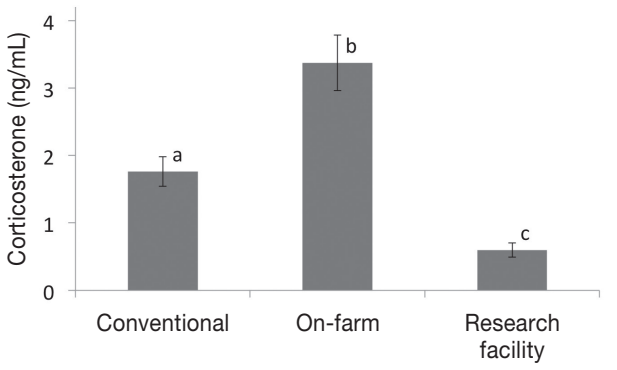

Figure 4. Corticosterone concentration (ng/mL) in the same serum samples as in Figure 3.

evidence that behavioral distress during the on-farm handling for blood sampling predicted the trim loss for either treatment group [$F(2,8) < 0.7$, $P > 0.53$ for both] or the combined group [$F(2,19) = 1.41$, $P = 0.27$]. Split carcass weights were, however, smaller after transport [245.91 ± 8.06 kg versus 274.6 ± 7.0 kg, t (unequal variances) = 2.68, df = 19.6, $P < 0.015$]. Split carcass weights are not affected by emptying of gut contents, but could be affected by dehydration, in spite of the drinking water that was made available overnight. However, as there was no live weight obtained on-farm before exsanguination, differential assignment of individuals to the 2 groups could not be ruled out as a source of the weight differential.

Serum biomarkers of muscle injury

For the 22 heifers handled and sampled on-farm, both measures of muscular damage, AST, and CPK, were positively associated ($R^2 = 0.39$, $P < 0.025$). Although there were no clinical signs of myopathy, one transported heifer had a laboratory-diagnosed myopathy with CPK of 31 152 U/L and AST of 4189 U/L, which would indicate severe heavy muscle damage in a dairy cow (22). That individual also had the largest trim losses (14.2 kg; 6.23%). When that individual was excluded, there was a significantly larger variance for both CPK and AST in the animals that had been transported than in the animals that had been slaughtered on-farm (Bartlett test for unequal variances, both $P < 0.0005$). Serum aspartate aminotranferase was also higher in the transported animals (Non-parametric Wilcoxon, z approximation, $P < 0.04$). Serum glucose was higher in the on-farm bison heifers (20.4 ± 2.3 mmol/L) than in the animals transported and then rested for 18 h of lairage at the research facility [6.9 ± 0.5 mmol/L; t (unequal variances) = 5.77, df = 9.7, $P < 0.0002$]. Sampling order was also considered as an *ad hoc* variable in analyses when the day of sampling extended for several hours longer than had been anticipated, prolonging the disturbance on-farm, and increasing the time for muscle damage to be reflected in physiological measures. For the 22 heifers handled and sampled on-farm, there was a positive association between order of handling and serum CPK in the tail vein samples collected on-farm ($R^2 = 0.42$, $P < 0.02$; Figure 2). The second measure of muscle damage, AST, was not associated with sampling order ($P = 0.33$).

Glucocorticoid stress responses

Cortisol concentrations (25 to 60 ng/mL) were higher than corticosterone concentrations (0.5 to 7.0 ng/mL), with no change between on-farm handling and on-farm exsanguination samples (both $P > 0.1$). However, the 2 glucocorticoids responded differently to the 3 conditions. For cortisol, conventional slaughter was associated with the highest, then on-farm, then the research abattoir [$F(2,29) = 20.0$, $P < 0.0001$; Figure 3]. In contrast, corticosterone concentrations were highest in the on-farm group, and lowest in the research abattoir group [$F(2,29) = 25.8$, $P < 0.0001$; Figure 4]. Thus, the cortisol/corticosterone ratio was higher at the research abattoir (52.0 ± 6.7), than at the conventional abattoir (31.0 ± 3.0), which was higher than on-farm [12.1 ± 1.0; F unequal variances (2,14.3) = 31.6, $P < 0.0001$; Figure 5]. On-farm, glucose was inversely associated with cortisol concentration ($R^2 = 0.42$, $n = 11$; $P < 0.05$).

Discussion

Transport of bison to the research facility was associated with a significant increase in trim loss, even without consideration of additional losses due to shrinkage. This was not only because the animals transported were likely to accumulate muscle damage (13,17), but also because the on-farm slaughter followed disturbance so rapidly that injuries might not have developed into trim losses. Thus, from the perspective of ranch economics, carcass value was higher on farm because animals did not suffer shrinkage in transport (assumed, not measured), and valuable meat product was not lost as trim.

Muscle damage in bison began with the initial disturbance for handling (13). The long day of disturbance on-farm was a prolonged stressor for bison. Unfamiliar people were present, and animals were relocated from their grain-finishing pen to holding pens, and then moved into temporary social isolation for sampling. Animals that waited longer for that serum sample (over the course of the 8-hour day) had higher CPK levels.

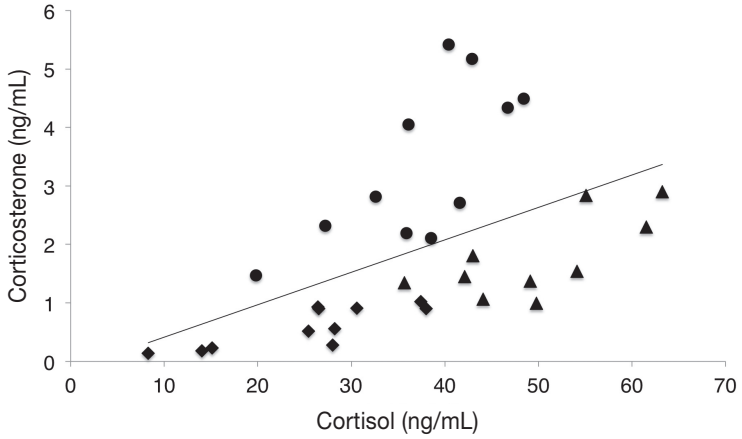

Figure 5. Association between cortisol and corticosterone concentrations within individual serum samples. (Conventional = ▲, On-farm = ●, Research facility = ◆). Linear regression for on-farm (slope = 0.12, $R^2 = 0.50$, $n = 11$; $P < 0.02$) was steeper than conventional (slope = 0.055, $R^2 = 0.49$, $n = 10$; $P < 0.03$) or research (slope = 0.03, $R^2 = 0.68$, $n = 11$; $P < 0.002$) facilities.

This increase might reflect CPK kinetics in bison, (i.e., heifers that were slaughtered earlier after mustering had less time for CPK released from damaged muscles to reach peak serum concentrations) or might indicate that animals held longer before slaughter experienced ongoing muscle damage. Serum glucose was also twice the upper limit on-farm, whereas serum glucose at the research abattoir was at the lower limit, relative to ranched bison sampled at a fixed location abbatoir (23). The lack of a drop-side on the chute prolonged handling for the time it took to move the animal to a region of the holding system with access for carcass recovery and for the killing shot. Thus, physiological measures of stress on-farm were likely to be elevated relative to reference values for an on-farm handling system that could incorporate the kill within the handling system.

Transport to the research facility and lairage increased muscle damage (13,15). Not unexpectedly, the single heifer with laboratory-diagnosed myopathy had the highest trim losses after transport to the research abattoir. However, when that individual was excluded, heifers that had been handled on-farm 48 h previously, transported, and left in lairage, still demonstrated a wide range of indicators of muscle damage. Thus, prolonged stress on-farm was associated with muscle damage and glucose mobilization, and, when combined with the additional stressor of transport, resulted in trim losses. Meat quality was not assessed in this study, but might also have been adversely affected (15,17,18).

Although cortisol was at higher concentrations than corticosterone, corticosterone values at exsanguination discriminated between the research abattoir (least disturbance, no unfamiliar bison, closest to theoretical baseline), the conventional abattoir (rapid processing) and the on-farm (prolonged handling stress) situations by showing a 6-fold difference, whereas the cortisol differential between locations was only 50%. Results were consistent with a hypothesis that cortisol concentrations quite rapidly reach a maximum when stress is sustained, whereas corticosterone concentrations continue to increase (24). Similarly divergent stress-responses for cortisol and corticosterone in diverse wildlife species (24), and in bison (25) have recently been described. Future studies of bison stress responses, therefore, should consider both cortisol and corticosterone quantitation, and the possibility that each adrenal steroid conveys different biological information during the stress response.

In spite of having an on-farm handling system designed for bison, it was clear that the bison were stressed by the on-farm handling and additionally stressed because it was not possible to complete the kill in the squeeze chute. A chute handling system with visual barriers (14), effective restraint with access to the head for a safe kill, accessible drop-sides, and ease of access for transfer into the multi-site abattoir would facilitate on-farm slaughter. However, the handling system alone cannot mitigate all injury and bruising in bison which have limited experience with handling systems (15). For example, 1 animal managed to become entangled in the fencing, and another experienced a horn de-gloving. Thus, potential advantages of on-farm slaughter for bison include reduced trim losses, reduced time for muscle damage to affect meat quality, and reduced duration of stress for the animals.

Acknowledgments

This research project was integral to the undergraduate DVM curriculum at the University of Calgary Faculty of Veterinary Medicine (UCVM) with components in the *Investigative Medicine* Area of Emphasis and the Professional Skills curriculum (http://vet.ucalgary.ca). Lars Jorgenson of Gate-to-Plate Food Services, Inc., Fort St. John, British Columbia obtained Alberta licensing specifically for this project. Alberta Agriculture provided the provincial inspector for the mobile abattoir. The authors are also grateful for the skilled technical contributions of the staff at the provincial and the federal abattoirs. CVJ

References

1. Shaw JH. How many bison originally populated western rangelands? Rangelands 1995;17:148–150.
2. Isenberg AC. The Destruction of the Bison: An Environmental History, 1750–1920. New York, New York: Cambridge University Press, 2000.
3. Gates CC, Freese CH, Gogan PJP, Kotzman M, eds. American Bison: Status Survey and Conservation Guidelines. Gland, Switzerland, IUCN. 2010. Available from: http://cmsdata.iucn.org/downloads/american_bison_report.pdf Last accessed June 5, 2013.
4. Canadian Agriculture Census data. Available from: http://www29.statcan.gc.ca/ceag-web/eng/community-agriculture-profile.action?varId=258&geoId=0 Last accessed June 5, 2013.
5. Gao F. Assessing the consumer acceptance and market potential of Alberta bison meat. MSc thesis. University of Alberta. Edmonton, Alberta. 2006.
6. Rule DC, Broughton KS, Shellito SW, Maiorano G. Comparison of muscle fatty acid profiles and cholesterol concentrations of bison, beef cattle, elk and chicken. J Anim Sci 2002;80:1202–1211.
7. Province of Alberta Meat Inspection Act, Alberta Queen's Printer, Edmonton, Alberta (Revised Statutes of Alberta 2000; Chapter M-9; Current as of November 1, 2010). Available from: www.qp.alberta.ca/documents/Acts/M09.pdf Last accessed June 5, 2013.
8. Meat Inspection Act (R.S.C., 1985, c. 25 (1st Supp.)), Government of Canada, Department of Justice, (Act current to 2012-10-02 and last amended on 2005-12-12). Available from http://laws-lois.justice.gc.ca/eng/acts/M-3.2/ Last accessed June 5, 2013.
9. Kremeniuk T. Meeting EU and consumer requirements important if Canadian bison industry is to grow. Bisonlink: Canadian Bison Association, August 2007. Available from: http://www.canadianbison.ca/producer/news_events/documents/BisonLinkAug07.pdf Last accessed June 5, 2013.
10. Costa LN. Short-term stress: The case of transport and slaughter. Italian J Anim Sci 2008;8:241–252.
11. Grandin T. Assessment of stress during handling and transport. J Anim Sci 1997;75:249–257.
12. Gruber SL, Tatum JD, Engle TE, Chapman PL, Belk KE, Smith GC. Relationships of behavioral and physiological symptoms of preslaughter stress to beef *longissimus* muscle tenderness. J Anim Sci 2009; 88:1148–1159.
13. Grandin T. Habituating antelope and bison to cooperate with veterinary procedures. J Appl Anim Welfare Sci 2010;3:253–261.
14. Canadian Agri-food Research Council (CARC). 2001. Code of practice for the care and handling of farm animals: Bison. Available from: http://www.nfacc.ca/codes-of-practice/bison Last accessed June 5, 2013.
15. Galbraith JK. Meat characteristics and stress of bison slaughtered in a mobile or stationary abattoir. PhD thesis. University of Alberta, Edmonton, Alberta. 2011.
16. McNally PW, Warriss PD. Recent bruising in cattle at abattoirs. Vet Rec 1996:126–128.
17. Ferguson DM, Warner RD. Have we underestimated the impact of preslaughter stress on meat quality in ruminants. Meat Sci 2008;80:12–19.
18. Schaefer AL, Stanley RW, Tong AKW, et al. The impact of antemortem nutrition in beef cattle on carcass yield and quality grade. Can J Anim Sci 2006;86:317–323.
19. Jorgenson L. Mobile slaughter fights government. The Western Producer. March 6, 2008:118.
20. US Department of Agriculture. USDA to host red meat mobile slaughter unit information session. US Department of Agriculture News Release #0318.10, 2010. Available from: http://www.usda.gov/wps/portal/usda/usdahome?contentidonly=true&contentid=2010/06/0318.xml Last accessed June 6, 2013.
21. Koren LZ, Ng ESM, Soma KK, Wynne-Edwards KE. Sample preparation and liquid chromatography-tandem mass spectrometry for multiple steroids in mammalian and avian circulation. PLoS One. 2012; 7:e32496 DOI: 10.1371/journal.pone.0032496
22. Guard C. Musculoskeletal Disorders. Chapter 11. In: Divers TJ, Peek SF, eds. Rebhun's Diseases of Dairy Cattle. St. Louis, Missouri: Saunders Elsevier, 2008:467–503.
23. Sikarskie JG, Schillhorn Van Veen TWS, van Selm G, Kock MD. Comparative blood characteristics of ranched and free-ranging American bison *(Bison bison)*. Am J Vet Res 1990;51:955–957.
24. Koren L, Whiteside D, Fahlman A, et al. Cortisol and corticosterone in stressed, cortisol-dominant wildlife. Gen Comp Endocr 2012; 177:113–119.
25. Toosi BM, Gratton G, McCorkell RB, et al. Effects of pipothiazine palmitate on handling stress and on the characteristics of semen collected by electroejaculation in bison *(Bison bison)* bulls. Anim Reprod Sci 2013 Feb 8. pii: S0378-4320(13)00035-3. doi: 10.1016/j.anireprosci.2013.01.012.